Electric Power Demand and Emerging Technology in Highly-sophisticated Electric Power Systems

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In the last few years, the increase of the electric power demand has been remarkable, especially in Asia district. In such trend, the electric power system of Japan has been supplied with high quality, high reliability and highly-stabilized electric power. This is supported by highly-sophisticated electric power system which prides oneself on high voltage and large capacity. In this paper, outlines of these technologies are described. And, newest technology trends such as electric power liberalization, innovation of dispersed power source, effective utilization of natural energy are also explained. In addition, the global standards are important to make the technological level of Japan to be the world one in future.

Keywords : electric power system, power generation, transformer, gas insulated switchgear, surge arrester, power system relaying, diagnostics, monitoring

1. Introduction

Japan's electric power systems represent a sophisticated high-voltage, large-capacity ones that can supply electric energy with stability, reliability and high efficiency across a large-scale network. At the same time, recent trends toward worldwide deregulation of the power industry has encouraged intensive discussion about more efficient use of equipment and reasonable power prices to meet economic growth, while ensuring system safety. Increasing public awareness about environmental issues and global warming have drawn significant attention to diverse power sources including wind-power systems, solar cells, fuel cells and so on. It is known that environmental awareness and rapid progress of information technology have caused significant changes in the electric power business.

This paper will review the development of sophisticated electric power equipments that meet the high performance criteria of our rapidly evolving power system, and outline future research challenges for providing a more comfortable living space and social welfare.

2. Projecting World Population and Energy Demand

The world population as of 2000 was about 6.0 billion and is expected to reach 7.0 billion in 2010, 7.9 billion in 2020 and as high as 9.0 billion in 2050 ⁽¹⁾. The key feature of this projection is that population growth will be dominated by developing rather than developed countries.

Figure 1 shows the results and projections of year-by-year primary energy demand throughout the world ⁽²⁾.

In the coming years, total amount of oil, natural gas, coal, new energy sources such as wind power, hydrogen, sunlight, and biomass, in addition to nuclear power will increase as shown in fig.1⁽²⁾. Thus we have to pay attention to the technical trends behind new energy sources when considering the future of power systems.

Figure 2 shows recent trends in power demand in Asia. Power

demand continues to grow steadily in every country, but particularly in China. By 1995, China's power demand already exceeded that of Japan. India's and Korea's power demands have shown an increase to about half and one fifth of Japan's level respectively.

Fig. 1. World primary energy demand (Ref.(2))

Fig. 2. Trends in power demand in Asia

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3. Ensuring Power Quality and Technological Development

Japan's power systems have the following features:

- (1) There is massive power demand in major cities like Tokyo, Nagoya, Osaka and Kitakyushu.
- (2) Power is transported at high voltages with high capacities.
- (3) The service area is divided into the eastern 50 Hz area and western 60 Hz area.
- (4) Daytime power use is twice that of nighttime.

Table 1 is a summary of these basic technical measures classified by cost effectiveness, reliability, and power quality as they relate to power systems and devices⁽³⁾.

To maintain the power quality and reliability of these power systems, the following technical measures are being taken.

- (a) Constant voltage : Extended use of the On Load Tap Changer (OLTC)
- (b) Constant frequency : Coordinated operation between the eastern and western areas (50 Hz and 60 Hz)
 - Control of power systems operation
 - Adoption of power electronics
- (c) Uninterruptible supply
 - Upgrading of the protective relay method
 - Adoption of a high-speed re-close circuit
 - (Pre-announced blackout)

4. Recent Technological Developments

For the sake of brevity, this paper provides only a brief review of recent technological topics related to power generation, power transmission and transformation, and surge protection systems.

4.1 Power Generation The heat efficiency of thermal-power generation exceeds 50%, as the gas turbine-steam turbine combined cycle is achieved. This level of efficiency is attained by raising the gas-turbine inlet temperature to near 1,500°C (1,450°C), developing high-performance cooling vanes of the all air-film cooling architecture, developing Ni-based ultra-alloy heat resistant material and one-directional solidification alloy applicable to large turbine vanes, making the combustion temperature uniform by sufficient mixing of air with fuel, and developing a steam-cooling, high-temperature, low nitrogen-oxide furnace where the thermal efficiency is improved by the steam cooling and steam-turbine steam collection methods.

The boiling water reactor (BWR) and the pressurized water reactor (PWR) are used for nuclear power generation. In the latest advanced boiling water reactor (ABWR), construction costs have been reduced and a high output of 1,356 million kW has been

attained by employing a self-contained reactor with built-in recycling pump, improving the control rods' operation mechanism and adopting a ferro-concrete reactor vessel.

Meanwhile, in the variable-speed pumped-storage system, the combination of a power generator and semiconductor controller allows smooth plant operation at a high capacity.

4.2 Transmission/Transforming Equipment The gas-insulated switchgear (GIS) using SF₆ gas has widely used in many countries due to its excellent performance. A one-point interrupting chamber has been developed for the 550kV-class gas circuit breaker, as well as lower voltage class, significantly contributing to equipment downsizing. Figure 3 is an example of a GIS that reduces the necessary gas amount by employing a one-point gas circuit breaker to decrease its environmental burden. It also saves installation space through a layered configuration of the equipments.

Substations in large cities in Japan are built underground because land for substations is difficult to obtain. In such underground substations, gas insulated transformers have been in use in the interest of fire prevention and the reduction of construction costs. Figure 4 shows an example of gas insulation transformers.

Improvements in gas insulation technology and cooling gas flow analysis technology have significantly contributed to the successful commercialization of the high-capacity gas insulated

Fig. 3. Downsized, environmentally friendly 550 kV gas insulated switchgear

Fig. 4. Large-capacity gas insulated transformer (300 MVA-275 kV)

Table 1. Technical points to meet growing power demand

Item	Power System	Equipment
Pursuit of cost effectiveness	Higher capacity, Higher voltage, Enhanced insulation	Lower test voltage, Smaller devices
Pursuit of reliability	Power System Co-operation	Rational withstand voltage test
Pursuit of power quality	High-speed re-close circuit	On Load Tap Changer

Fig. 5. SEM pictures of the conventional ZnO device (left) and the developed high gradient model (right)

Fig. 6. High gradient ZnO surge arrester for 500 kV GIS (Rated voltage for continuous use 420 kV, rated discharge current 10 kA, lightning impulse voltage upper limit 870 kV (at 10 kA))

transformer.

An all-gas underground substation that has coupled the gas insulation transformer with the gas insulated switchgear is already in operation.

The ZnO surge arrester for power systems was invented in Japan. This surge arrester with its excellent non-linearity has found employment as a surge protector in a wide variety of electric equipment, including electric trains such as the bullet train “Shinkansen”. With its established record of long-term reliability, it is now being used in many countries.

Although the operating voltage of the conventional device made of ZnO grains of 10 μm or so is about 200 V/mm, the new device made of ZnO grains half the size of conventional ones has a operating voltage as high as about 400 V/mm. Figure 5 shows their SEM pictures, demonstrating that the ratio of boundary layers working as high resistance has increased in the fine grain model. Such devices of high operating voltage help us downsize surge arresters. Figure 6 shows the external view of such a high gradient ZnO surge arrester developed for the 500 kV GIS⁽⁴⁾.

Porcelain bushing insulators have been used for a long time. In recent years, a composite-type bushing employing the silicone rubber housing outside the FRP body has been developed as well. A 300kV class model has already been commercialized in Japan, and even 550kV class composite bushing will come into use before long.

Fig. 7. Long-term field test of the 550kV composite-type bushing in a heavy snowfall area

Fig. 8. Directly molded polymer type surge arrester with a gap for 66kV/77kV power transmission lines

Figure 7 illustrates a long-term field test of the 550kV composite-type bushing in a heavy snowfall area in Japan. Its performance quality was proven to be highly stable even under such adverse weather conditions⁽⁵⁾.

New type of surge arrester using a directly molded polymer has already been developed and used. Figure 8 shows a surge arrester with a gap that was developed for use in 66-kV/77-kV power transmission lines. It accomplished small and lightweight design essential to the transmission line arrester thanks to the directly molded structure⁽⁴⁾.

4.3 Control of Over-Voltage Over-voltage can be generated in power lines due to lightning surges as well as switching of various switches such as disconnector or circuit breaker. To control over-voltage, surge arresters are employed to absorb surge energy; residual charges that are a cause of over-voltage are removed with a line reactor; resistance or damping resistance devices are installed to prevent circuit resonance; and transient phenomena are prevented by synchronized switching-on or switching-off for circuit breaker.

These techniques can prevent over-voltage from occurring, minimizing the decrease in device insulation levels and their influence upon peripheral components. In addition, because component wear, mainly caused by arcing during switching on/off, can be reduced, devices can remain useful for a longer period of time.

Fig. 9. Protection control system Utilizing the Web and GPS

Fig. 10. Time-frequency analysis using the Wavelet transform

4.4 Power System Relaying In addition to the conventional fiber optic communications system, a more reliable Web-based or GPS-based protection monitoring system has been developed in the field of power system relaying, as shown in Fig. 9. This system, utilizing existing Internet lines, allows wide-ranging protection, monitoring, and control. This system also has the added advantage of being easy to build.

At the same time, the formation of a power network corresponding to the wider acceptance of distributed power sources, particularly the combination of DC systems and line protection, should be investigated.

4.5 Diagnostics and On-Line Monitoring Diagnostics and on-line monitoring for condition-based maintenance (CBM) are the emerging technology from the high reliable, low cost points of view. Regarding the technological aspects, studies on early-stage fault-detection techniques, and on increased operation life for power equipment and devices, should be deepened, while placing importance on further advances in insulation-diagnoses techniques.

Figure 10 shows one example of time-frequency analysis of Lamb waves caused by partial discharges in GIS⁽⁷⁾. Propagation properties of Lamb waves in GIS tank were clarified by the analysis for acoustic signals excited by partial discharge and new techniques are proposed for identification of the defect location in GIS.

Data mining technology and construction of data base for partial discharge are also important from the practical point of view.

5. Deregulation of the Power Industries and Technological Developments

Japan's government will allow any company to join the power generation, transmission, and distribution businesses, in order to establish a more competitive industry and encourage lower-priced power. On the other hand, as demonstrated by the power crisis seen in the United States and European countries, deregulation can have some negative aspects, such as frequent problems in supply capacity as well as hiked power rates. Power businesses are likely to reduce investment in new power generation equipment and power distribution equipment to maximize their profits. Thus, intensive discussion of power quality, including supply-side reliability and risk management, is necessary to create broad agreement on deregulation⁽⁷⁾. For free trade of electric power, fairness based on disclosure as well as ensured safety is the key. Discussion regarding these aspects of deregulation will need to be deepened in the future.

6. The International Standardization Activities

There are two standards; de facto standard and de jure standard. In the business strategy, the mutual certification is quite important, therefore, international standardization activities are fundamentally a part of corporate activities.

The promotion of standardization policy mixed with industrial policy and technological policy is strongly desired.

7. Contribution to Enhanced City Functions and Improved Infrastructure⁽⁸⁾

Paris is praised as one of the world's most beautiful cities, drawing as many as 70 million visitors a year which is a significant boon to the local economy. The urban planning for Paris was based on the assumption that it would receive many visitors. In Japan, with the ongoing dearth of births and the aging population, improvement of city functions is of prime importance for ensuring a comfortable living space. Thus infrastructure including power, gas, water lines and railways and so on must be constructed in accordance with long-term city planning that takes into consideration the appearance of towns and cities. Such discussion, from the viewpoint of urban planning and social welfare, will become increasingly important in the years ahead.

8. Conclusions

Electric power is an essential part of the national and international infrastructure in a world with a constantly growing population, particularly in developing countries. In Japan, faced with the problem of declining births and graying population, further improvements in power quality, assisted by deregulation, are expected. Asian countries are highly interested in Japan's power technologies and there is strong demand for technological cooperation and consulting. In fact, many companies have already been involved in such activities.

Meanwhile, infrastructure such as power, gas, water and transportation need further improvement to create a more comfortable urban lifestyle together with the general welfare. This requires discussion beyond the scope of simple deregulation designed to encourage free power trade. We have to consider the future of environmentally friendly power systems designed in conjunction with long-term urban planning. As pointed out in this paper, most technological issues can be solved once a solid

long-term vision has been established. If power engineers continue to carefully review and analyze environmental issues and human activities, a more sophisticated social infrastructure can be built.

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